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An overview of biofuels from energy crops: Current status and future prospects

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ABSTRACT

Energy crops constitute significant potential for meeting the future energy need worldwide. In addition, agricultural lands offer an alternative to the agriculture which is referred to as energy farming. The studies on energy crops in biofuel production show that they are quite an economical and environmentally beneficial way of sustainable energy production. Today most of the developed countries use staples such as corn, sugar beet, soybean, rapeseed, and wheat in order to obtain energy. Moreover, bioethanol is mostly produced from sugarcane and corn and biodiesel from oilseed plants. Therefore, these produced raw materials compete with food and feed production. Consequently, the use of those energy crops which are used as food products for biofuel production is an important issue which must be considered in terms of the current food safety. Some energy crops, such as miscanthus, switchgrass and sweet sorghum, that are called C4 crops, can grow with high biomass yield even in infertile land. Thus, these crops are used in energy farming – a new type of agriculture. Furthermore, C4-type crops possess the features of resistance to aridity, high photosynthetic yield and a high rate of CO_2 capture when compared with C3 crops. In conclusion, C4 crops tend to produce more biomass than C3 crops. Therefore, these crops are investigated, focused on, and elaborated on in this paper.

This study aims to present a comprehensive review on the production of biofuels from lignocellulosic agricultural products and promising energy crops. Thus, the energy crops to be used as raw materials for biofuels today and in the future are investigated. In addition, it is intended to highlight the energy crops used as staples by discussing them in detail for biofuel production. The energy crops which are promising in biofuel production, particularly non-staple miscanthus and sorghum, are presented in detail as they are non-food crops and have a high yield. Furthermore, the energy crops used as raw materials for bioenergy today and their potential are compared both worldwide and in Turkey.

Contents

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1. Introduction

The use of biomass to produce energy is only one form of production of renewable energy that can be utilised to reduce the impact of energy production and use on the global environment [1].

Biomass has the largest potential and can only be considered as the best option for meeting the demand and insurance of future energy/fuel supply in a sustainable manner. The modernization of biomass technologies leading to more efficient biomass production and conversion is one possible direction for efficient utilization of biomass resources. Agricultural biomass is a relatively broad category of biomass that includes the food based portion (oil and simple carbohydrates) of crops (such as corn, sugarcane, beets) and the non-food based portion (complex carbohydrates) of crops (such as the leaves, stalks, and cobs of corn stover, orchard trimmings, rice husk, straw), perennial grasses, and animal waste [2].

Energy can be obtained from biomass in five ways: production of crops which yield starch, sugar, cellulose and oil; solid waste which can be burnt; anaerobic digesters which produce biogas which can be used to generate heat/electricity; landfill production for methane; and biofuel production which includes ethanol, methanol, biodiesel and their derivatives [3].

Today, there are strong incentives to encourage an increased use of renewable fuels in the transport sector worldwide. Incentives exist within energy, climate and agricultural policies in several countries to promote further progress in the use of biofuels [4].

Every year our earth′s atmosphere receives more than 15 billion tones of CO_2. The combustion of fossil fuels is a big contributor to the increase in the level of CO_2 in the atmosphere which is directly associated with global warming [5,6].

One of the major drivers for worldwide biofuels development is the concern about global climate change that is primarily caused by the burning of fossil fuels. There is substantial scientific evidence that the accelerating global warming is a cause of greenhouse gas emissions. One of the main greenhouse gases is carbon dioxide [7].

Plant biomass has been known for decades to be one of the most promising renewable energy sources that can be used for production of biofuels, since it is an abundant resource, has low CO_2 emissions and low cost. Biomass provides approximately 14% of the total world-wide energy needs and represents an important contributor to the world economy. Furthermore, plant biomass can contribute to a stabilization of farmers′ incomes, and can maintain and improve ecological and social sustainability [8].

Today the production of biofuels from biomass as a renewable energy resource is quite important since it is both a clean energy resource and related to the environment, economy, agriculture, and rural development. Moreover, the development of biofuels from energy crops has a critical role in the development of the world economy and the reduction of global climate change.

This paper intends to summarize the current status of, and the future perspective on, the production of biofuels from the energy crops used as raw materials both worldwide and in Turkey. Additionally, it also encompasses the classification of energy crops as raw materials for biofuels all around the world, their potential for production, characteristics of the new promising energy crops, and their status in the future.

2. Current biofuel production in the World

In 2010 worldwide biofuel production reached 105 billion liters (28 billion gallons US), increasing by 17% from 2009, and biofuels provided 2.7% of the world′s fuels for road transport, a contribution largely made up of ethanol and biodiesel [9].

Biofuel consumption in transport continued to increase in the European Union. As it can be seen from Table 1, it stabilised at around 13.6 Mtoe (millions of tones of oil equivalent) in 2011, compared to 13.2 Mtoe of consumption in 2010. It is too early to say whether all this consumption meets the Renewable Energy Directive′s sustainability criteria, because the majority of the sustainability systems were yet to be set up in 2011 [10].

Table 1 shows biofuel consumption for transport in the European Union in 2010 and also, Table 2 shows biodiesel production in the European Union between 2009 and 2010 [10].

Table 1
Biofuel consumption for transport in the European Union in 2010 (in toe) [10].

Countries	Bioethanol	Biodiesel	Others	Total consumption
Germany	746,776	2,281,791	53,908	3,082,475
France	490,112	2,138,627	–	2,628,739
Spain	233,179	1,192,627	–	1,425,807
Italy	139,940	1,254,013	–	1,393,953
United Kingdom	316,495	823,660	–	1,140,155
Poland	187,184	710,713	3180	901,078
Austria	63,457	354,858	119,175	537,489
Sweden	203,943	198,340	49,355	451,638
Belgium	52,119	305,917	–	358,036
Portugal	0	325,982	–	325,982
Czech Republic	61,262	172,494	–	233,756
Romania	45,142	185,583	–	230,725
Netherlands	134,136	94,559	–	228,695
Slovakia	45,142	132,560	–	177,701
Hungary	57,615	117,009	–	174,625
Finland	73,517	62,745	58	136,320
Greece	0	124,810	–	124,810
Ireland	27,324	79,249	2036	108,610
Lithuania	10,412	34,731	–	45,144
Slovenia	2904	41,724	–	44,628
Luxembourg	720	40,043	–	40,763
Denmark	34,179	820	–	34,999
Bulgaria	0	34,387	–	34,387
Latvia	8419	18,698	–	27,117
Cyprus	0	14,944	–	14,944
Malta	0	884	–	884
Estonia	0	0	–	0
Total EU 27	**2,933,977**	**10,741,771**	**227,712**	**13,903,460**

As of 2011, mandates for blending biofuels exist in 31 countries at the national level and in 29 states/provinces [11]. According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050 [12].

Table 2
Biodiesel production in the European Union between 2009 and 2010 (in thousands of tones) [10].

Countries	2009	2010
Germany	2539	2861
France	1959	1910
Spain	859	925
Italy	737	706
Belgium	416	435
Poland	332	370
Netherlands	323	368
Austria	310	289
Portugal	250	289
Finland	220	288
Denmark/Sweden	233	246
Czech Republic	164	181
Hungary	133	149
United Kingdom	137	145
Slovakia	101	88
Lithuania	98	85
Romania	29	70
Latvia	44	43
Greece	77	33
Bulgaria	25	30
Ireland	17	28
Slovenia	9	22
Cyprus	9	6
Estonia	24	3
Malta	1	0
Luxembourg	0	0
Total EU 27	**9046**	**9570**

Note: 1 tone of biodiesel is equivalent to 0.8837 toe.

United States and Brazil are the two dominant producer and user of bioethanol. World of bio-ethanol production was approximately 87.5% carried out by these two countries. The USA has allocated a significant portion of its highly productive agricultural areas to corn production in order to produce low-cost bioethanol, whereas Brazil uses sugar cane as a raw material for bioethanol production. The foreign-owned bioethanol market in Brazil is the largest exporter with a share of 25%. The second exporter of bioethanol is the US, followed by France and the United Kingdom. EU countries usually trade among themselves usual [13].

Most countries in the world, especially the US and EU countries, support various forms of biofuel production and thus production increases every year. Table 3. shows biofuels′ targets of several countries [13].

Given the further of the target, consumption projections can only be hazarded. If we assume that the current increase in consumption remains stable until 2020 (i.e. up 1.7 Mtoe per annum), bioethanol and biodiesel consumption, both first- and second generation, could easily exceed the current NREAP targets by reaching 30.8 Mtoe instead of 28.4 Mtoe. The NREAP plans have built in allowance for the consumption of 7121 ktoe of bioethanol. Fig. 1 shows the comparison of the current biofuels consumption for transport trend against the NREAP (National Renewable Energy Action Plan) roadmaps [10].

The transition to biofuels requires the production of more crops. Depending on the location, countries choose different crops [14]. Maize (USA) and wheat (Northwest Europe) as feedstock for ethanol perform poorly for nearly all indicators. Sugar beet (Northwest Europe), cassava (Thailand), rapeseed (Northwest Europe) and soybean (USA) take an intermediate position.

2.1. Bioethanol

Global ethanol fuel production reached 86 billion liters (23 billion gallons US) in 2010, with the United States and Brazil as the world′s top producers, accounting together for 90% of the

Table 3
Biofuels′ targets of several countries [13].

Countries	Years	Target	Feedstock
U. S. A	2012 2013 2020 2005	28 Billion ethanol 1 Billion liters of cellulosic ethanol 25% Ethanol 2% Biodiesel	Corn, soybean oil, sorghum, cellulosic sources in the future
Brazil	2012 2013 2020	25% Ethanol and B2 B5 (2.4 billion biodiesel) B20	Soybean, sugarcane, palm oil
EU	2005 2010 2020	2% 5.75% 10%	Rapeseed, sunflower, wheatsugar beet, barley
China	2010 2020	1.5–2 Million biodiesel 10% Ethanol (=8.5 million tones) 10.6–12 million biodiesel	Corn, cassava, sweet potato, rice, jatropha
Thailand	2012	10% Biodiesel	Cassava, molasses, sugarcane, soybean, coconut, jatropha, peanut
Canada	2010 2012	5% Ethanol 2% Biodiesel	Corn, wheat
India	2012 2017	5% Biofuel 10% Biofuel	Molasses, sugarcane in the future, jatropha
Australia	2010 2012 2017	350 Million liters of biofuel 10% Ethanol and 10% biodiesel 20% Ethanol and 20% biodiesel	Wheat, sugarcane, molasses, palm oil, cotton oil
Japan	2010 2020 2030	360 Million liters biofuel 6 billion liters biofuel 10% Biofuel	Imported ethanol, rice bran and

global production. World fuel ethanol production, 1995–2010 (millions of gallons) is shown in Fig. 2 [9].

The United States and Brazil remain the two largest producers of ethanol. In 2010, the United States generated 49 billion liters, or 57% of global output, and Brazil produced 28 billion liters, or 33% of the total output. Corn is the primary feedstock for US ethanol, and sugarcane is the dominant source of ethanol in Brazil [9]. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil. The current plant design does not provide for converting the lignin portion of plant raw materials to fuel components by fermentation [9].

The US produces more fuel ethanol than any other country; Brazil produces the second most. Together, the US and Brazil produced a little over 86% of the world's fuel ethanol in 2010. In 2011, global production of bioethanol reached 22,946.87 billion gallons, from the 12.1 billion gallons produced in 2005 [15].

Fig. 3 shows world fuel ethanol production by country in 2010 and Fig. 4, shows world fuel ethanol production in 2011 [15]

It is given that sugarcane, sugar beet and maize are currently energy crops which are widely used in feedstocks for bioethanol production.

2.1.1. *Sugarcane for bioethanol*

Brazil is the largest single producer of sugarcane with about 27% of global production and a yield of 18 dry mg/ha. The highest yield occurs in Peru, which produces more than 32 Mg of dry sugarcane per hectare [16]. Bioethanol production from sugarcane is very economical in Brazil because of two primary reasons. Brazil dropped the support of sugar prices to support the bioethanol industry with government established mandates for the blending of bioethanol with gasoline. This drastically lowered the cost of the feedstock, sugarcane, and created a demand for and supported the price of bioethanol [17]. Fig. 5 shows the top 10 sugarcane producers in the world in 2009 [18].

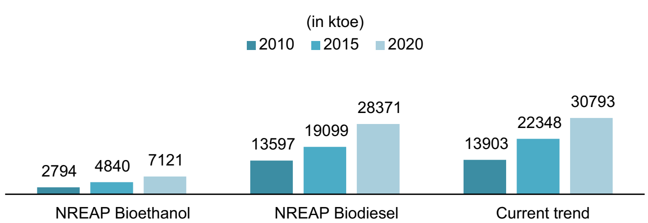


Fig. 1. Comparison of the current biofuels consumption for transport trend against the NREAP roadmaps [10].

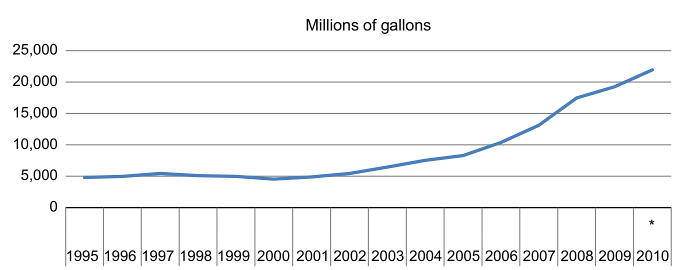


Fig. 2. World Fuel Ethanol Production, 1995–2010 (millions of gallons) [9].

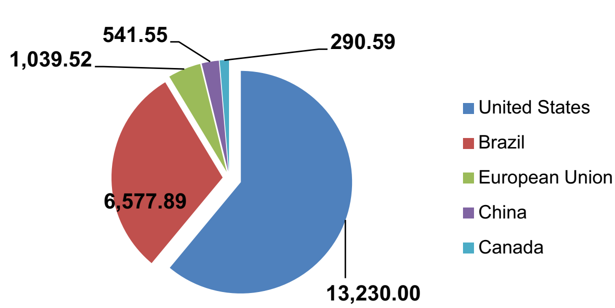


Fig. 3. World fuel ethanol production by country in 2010 (millions of gallons) [15].

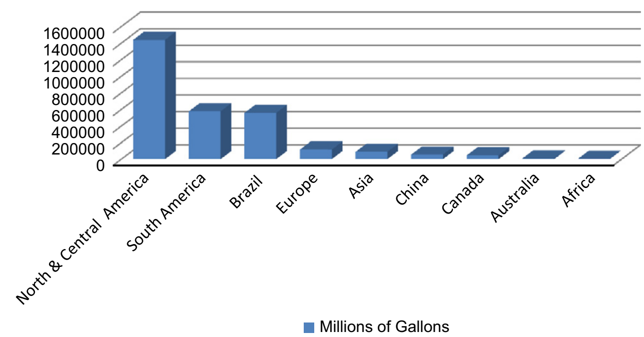


Fig. 4. World fuel ethanol production in 2011 [15].

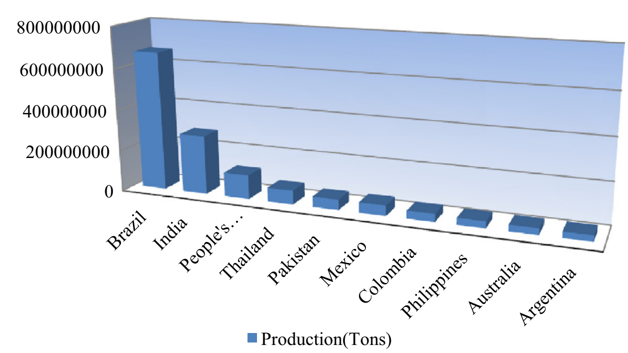


Fig. 5. Top 10 sugarcane producers in the world in 2009 [18].

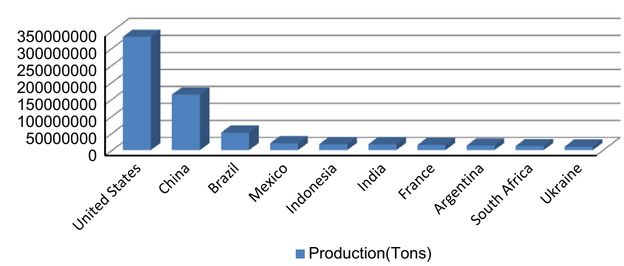


Fig. 6. Top 10 maize producers in the world in 2009 [20].

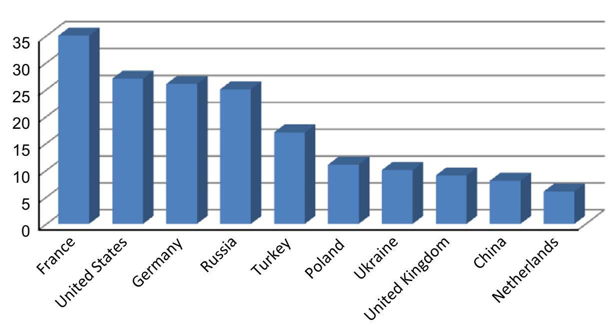


Fig. 7. Top 10 sugar beet producers in the world in 2009 (million metric tons) [21].

Table 4
Production capacity of the main European bioethanol producers in Europe in 2010 (in millions of liters) [10].
Source: EurObserv′ER (2011).

Company	Location of the units	Number of plants	Production of capacity	Raw materials
Abengoa	Spain (4) United States (6) Brazil (2) France (1) Netherlands (1)	14	3180	Sugarcane, barley, wheat, cereals, raw alcohol, maize, lignocelluloses
Tereos	France (6) Brazil (6) Belgium (1) Czech Rep. (1)	14	1700	Sugar juice, wheat, sugarcane
Crop energies	Germany (1) France (1) Belgium (1)	3	760	Sugar juice, cereals, wheat
Cristanol	France (4)	4	540	Sugar juice, wheat, sugar beet, glucose, raw alcohol
Agrana	Austria (1) Hungary (1)	2	410	Wheat, maize
Ensus	UK (1)	1	400	Wheat
Verbio	Germany (2)	2	300	Sugar juice, cereals

Table 5
Liquid biofuel production and blending targets for selected countries [23].

Country	Feedstock		2007 Production (million liters)		Blending targets
	Ethanol	Biodiesel	Ethanol	Biodiesel	
Brazil	Sugarcane, palm oil	Castor seed	18,798.2	242.6	25% Blending ratio of ethanol with gasoline (E25) in 2007; 2% blend of biodiesel with diesel (B2) in early 2008, 5% by 2013
Canada	Corn, wheat, straw	Animal fat, vegetable oils	1000.0	96.1	5% Ethanol content in gasoline by 2010; 2% biodiesel in diesel by 2012
China	Corn, wheat, cassava, sweet sorghum	Used and imported, vegetable oils, jatropha	1599.9	113.2	Five provinces use 10% ethanol blend with gasoline; five more provinces targeted for expanded use
EU	Wheat, other grains, sugar beets, wine, alcohol	Rapeseed, sunflower, soybeans	2302.8	6555.2	5.75% Biofuel share of transportation fuel by 2010, 10% by 2020
India	Molasses, sugarcane	Jatropha, imported palm oil	400.1	45.4	10% Blending of ethanol in gasoline by late 2008, 5% biodiesel blend by 2012
Indonesia	Sugarcane, cassava	Palm oil, jatropha	0	407.6	10% Biofuel by 2010
Malaysia	None	Palm oil	0	328.5	5% Biodiesel blend used in public vehicles; government plans to mandate B5 in diesel-consuming vehicles and in industries in the near future
Thailand	Molasses, cassava, sugarcane	Palm oil, used vegetable oil	300.2	260.4	Plans call for E10 consumption to double by 2011 through use of price incentives; palm oil production will be increased to replace 10% of total diesel demand by 2012
United States	Primarily corn	Soybeans, other oilseeds, animal fats, recycled fats and oil	24,597.6	1682.4	Use of 7.5 billion gallons of biofuels by 2012; proposals to raise renewable fuel standard to 36 billion gallons (mostly from corn and cellulose) by 2022

Brazil uses sugarcane to produce sugar and ethanol for gasoline–ethanol blends (gasohol), a locally popular transportation fuel. In Brazil, gasoline is required to contain at least 22%of bioethanol. This bioethanol is sourced from Brazil′s large sugarcane crop. The production of ethanol from sugarcane is more energy efficient than from corn or sugar beets or palm/vegetable oils, particularly if cane bagasse is used to produce heat and power for the process. Furthermore, if biofuels are used for crop production and transport, the fossil energy input needed for each ethanol energy unit can be very low. EIA estimates that with an integrated sugarcane to ethanol technology, the well-to-wheels CO_2 emissions can be 90% lower than conventional gasoline [19].

2.1.2. Maize/corn for bioethanol

Maize is increasingly used as a feedstock for the production of ethanol fuel. Ethanol is mixed with gasoline to decrease the amount of pollutants emitted when used to fuel motor vehicles. This process makes use of the whole plant rather than just the kernels as in the production of fuel ethanol. Maize is widely cultivated throughout the world, and a greater weight of maize is produced each year than any other grain. The United States produces 40% of the world′s harvest; other top producing countries include China, Brazil, Mexico, Indonesia, India, France and Argentina. Worldwide production was 817 million tones in 2009, more than rice (678 million tones) or wheat (682 million

tones) [20]. Fig. 6 shows the top 10 maize producers in the world in 2009 [20].

2.1.3. Sugar beet for bioethanol

Sugar beet, a cultivated plant of *Beta vulgaris*, is a plant whose tuber contains a high concentration of sucrose. It is grown commercially for sugar production. In 2009, France, the United States, Germany, Russia and Turkey were the world′s five largest sugar beet producers [21]. Fig. 7 shows top 10 sugar beet producers in 2009 [21].

The sales of E10, a fuel made up of 90% unleaded petrol and 10% bioethanol by volume, in some countries are behind the faster growth in bioethanol consumption (6.2% up on 2010) compared to biodiesel (2.4%). The European Commission would like E10 to be the main petrol fuel used in all the member states by 2013 [22]. Table 4 shows the production capacity of the main European bioethanol producers in Europe in 2010 [10].

The fuel directive includes not only a reference target of 5.75% of the market share for biofuels by 2010 but also recommends that member countries set an interim target of 2% for 2005. Table 5 shows liquid biofuels production and blending targets for selected countries [23].

2.2. Biodiesel

Biodiesel has recently experienced a major surge worldwide. The world′s largest biodiesel producer is the European Union, accounting for 53% of all biodiesel production in 2010 [9]. A rapid expansion in production capacity is being observed not only in developed countries like Germany, Italy, France, and the United States but also in developing countries like Brazil, Argentina, Indonesia, and Malaysia [24]. In Fig. 8, world biodiesel production between 2000 and 2010 [25] is shown.

A validation of the allocation of biodiesel/bioethanol crops was performed based on the current distribution of rapeseed in Germany. Germany currently produces almost exclusively biodiesel, which is dominantly derived from rapeseed [26].

Thecommonly accepted biodiesel raw materials include the oils from soy, canola, corn, rapeseed, and palm. New plant oils that are under consideration include mustard seed, peanut, sunflower, and cotton seed [27].

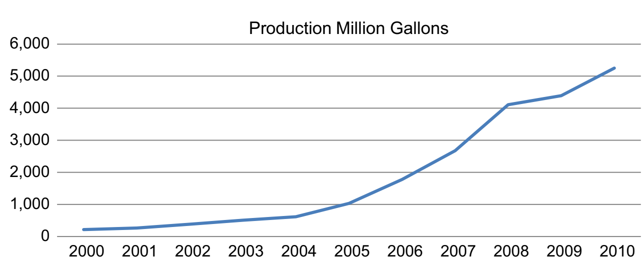


Fig. 8. World biodiesel production in the world between 2000 and 2010 [25].

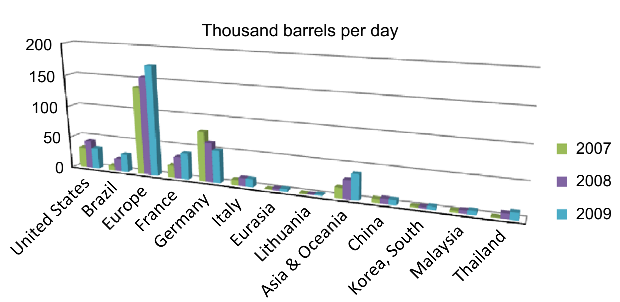


Fig. 9. World biodiesel production by region and selected countries between 2007 and 2009 (thousand barrels per day) [15].

The main producers of soybean are the United States (35%), Argentina (27%), Brazil (19%), China (6%) and India (4%) [28]. In addition, soybean is used mainly as animal feed.

Various oils have been used in different countries as raw materials for biodiesel production owing to their availability. Soybean oil is commonly used in United States and rapeseed oil is used in many European countries for biodiesel production, whereas coconut oil and palm oils are used in Malaysia and Indonesia for biodiesel production [27]. In India and southeast Asia, the jatropha tree (*Jatropha cursas*), karanja (*Pongamia pinnata*), and mahua (*M. indica*) are used as significant fuel sources [27]. Fig. 9 shows world biodiesel production by region and selected countries between 2007 and 2009 [15].

Biodiesel is still the main biofuel in European transport with a 78% share of total consumption, as compared to 21% for bioethanol. Biogas fuel consumption (0.5%) is still a purely Swedish phenomenon and vegetable oil consumption has reverted to a marginal status (0.5%) since Germany started taxing this product. Fig. 10 shows a breakdown of total EU 2010 biofuel consumption for transport by biofuel type and energy content [10].

2.3. Biogas

The production of biogas has become an attractive source of extra income for many farmers.

At the same time, environmental protection aspects have gained additional importance, so that anaerobic treatment processes have become a key technology for environmental and climate protection [29].

As a leader of biogas production, the German government has developed new process techniques and new technologies for the energetic use of biogas. Progress has been made in cultivating energy crops for biogas protection, in using new reactor systems for anaerobic digestion [29].

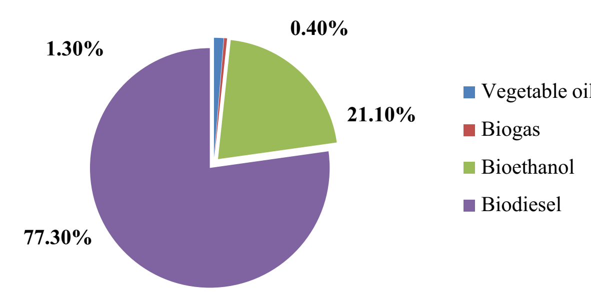


Fig.10. Breakdown of total EU 2010 biofuel consumption for transport by biofuel type and energy content [10].

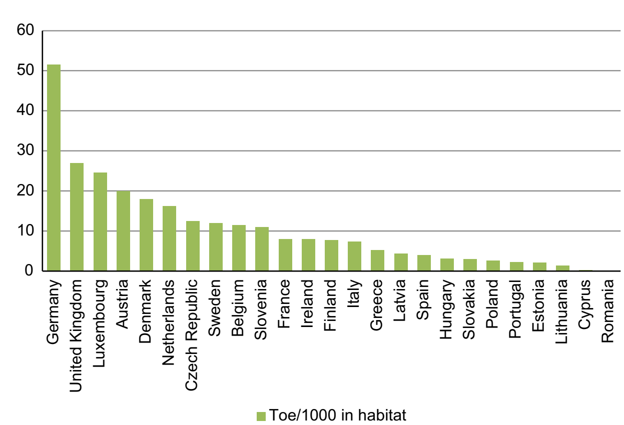


Fig. 11. Primary biogas energy production per in-habitat for each European Union country in 2009 (toe/1000 in-habitat) [30].

Table 6
Primary biogas energy output in the European Union in 2008 and 2009 (in ktoe) [30].

Countries	2008				2009			
	Landfill gas	Sewage sludge gas	Other biogas	Total	Landfill gas	Sewage sludge gas	Other biogas	Total
Germany	291.7	384.7	3553.1	**4229.5**	265.5	386.7	3561.2	**4213.4**
United Kingdom	1416.9	208.6	0	**1625.4**	1474.4	249.5	0	**1723.9**
France	379.3	45.5	28.3	**453.1**	442.3	45.2	38.7	**526.2**
Italy	339.8	3	67.2	**410**	361.8	5	77.5	**444.3**
Netherlands	44.4	48.8	132.5	**225.7**	39.2	48.9	179.8	**267.9**
Spain	157	19.7	26.6	**203.2**	140.9	10	32.9	**183.7**
Austria	4.8	21.9	147.8	**174.5**	4.9	18.9	141.2	**165.1**
Czech Republic	29.4	33.7	27	**90**	29.2	33.7	67	**129.9**
Belgium	46.7	1.5	39.4	**87.6**	44.3	2.1	78.2	**124.7**
Sweden	32.9	56.3	13.3	**102.4**	34.5	60	14.7	**109.2**
Denmark	6.4	20.2	67.2	**93.8**	6.2	20	73.4	**99.6**
Poland	34.2	59.4	2.6	**96.1**	35.5	58	4.5	**98**
Greece	28.3	5.1	0.2	**33.6**	46.3	12.2	0.2	**58.7**
Finland	34.1	10.9	0	**45**	30.6	10.7	0	**41.4**
Ireland	25.9	8.1	1.4	**35.4**	23.6	8.1	4.1	**35.8**
Hungary	2.1	8	11.7	**21.8**	2.8	10.3	17.5	**30.7**
Portugal	0	0	23	**23**	0	0	23.8	**23.8**
Slovenia	8.2	3.1	2.7	**14.1**	8.3	3	11	**22.4**
Slovakia	0.2	9.5	0.6	**10.3**	0.8	14.8	0.7	**16.3**
Luxembourg	0	0	9.2	**9.2**	0	0	12.3	**12.3**
Latvia	6.6	2.2	0	**8.8**	7	2.7	0	**9.7**
Lithuania	0.4	1.7	0.9	**3**	1.3	2.1	1.2	**4.7**
Estonia	2	0.9	0	**2.8**	2	0.9	0	**2.8**
Romania	0	0	0.6	**0.6**	0.1	0.7	0.5	**1.3**
Cyprus	0	0	0.2	**0.2**	0	0	0.2	**0.2**
European Union	**2891.1**	**952.8**	**4155.3**	7999.3	**3001.6**	**1003.7**	**4340.7**	**8346**

In a number of countries, the biogas market is stimulated by additional payments for the use of energy crops such as maize for methanisation. The use of maize as a biogas feedstock is particularly controversial because of the crop's high water food-print and demand for inputs, and the same argument applies to its use as a bio-fuel feedstock (Fig. 11) [30].

According to 2009 data by International Energy Agency, annual global liquid biofuel production had grown to 35.8 Mtoe and global biogas production reached 16.4 Mtoe in 2007 [31]. Germany has opted to develop agricultural methanisation plants by encouraging the planting of energy crops. As a result of this strategy, Germany is the leading European biogas producer, accounting for half of the European primary energy output (50.5% in 2009) and half of thebiogas sourced electricity output (49.9% in 2009) [31].

European Biogas Association (EBA) published its annual report on biogas production in 2010. According to EBAs data, Biogas Report 2011, there are approximately 7000 biogas plants currently in operation with an installed capacity of over 4000 MWel. The highest feed-in tariffs for kWh in 2010 were reported from Switzerland, Germany, and Italy [32].

The biogas sector has never before aroused as much attention as it does today. Across the European Union, the sector's progress becomes clear, as in 2009 primary energy growth leapt by a further 4, 3%. In addition, 8, 3 Mtoe of primary biogas energy is produced and also 25, 2 TWh of biogas electricity is produced in 2009 in the European Union. As it can be seen from Table 6 European primary biogas energy output rose to 8.3 Mtoe in 2009, which is 346.8 ktoe more than in 2008 and Fig. 12 shows primary biogas energy production per in-habitat for each European Union country in 2009 [30].

3. Production of biofuel potentials from energy crops in Turkey

Turkey has always been one of the major agricultural countries of the world. The importance of agriculture is increasing due to biomass energy being a major resource of Turkey. Like many developing countries, Turkey relies on biomass to satisfy much of its energy requirements [33].

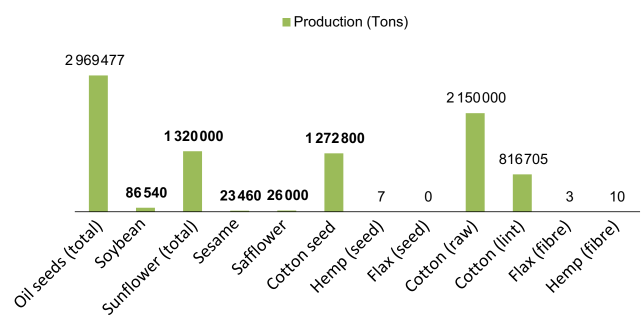


Fig. 12. Oil seed productions in Turkey in 2010 [39].

Geographically, Turkey is between the old world continents of Asia, Africa, and Europe. The country is located in the northern half of the hemisphere at a point that is about halfway between the equator and the North Pole. Turkey's geographical coordinates are 36–42° north latitude and 26–45° east longitude. It has a total area of 8,14,578 km^2 [34].

Turkey's geographical location makes it a natural bridge between the energy-rich Middle East and Central Asian regions. Because of the social and economic development of the country, the demand for energy, particularly for electricity, is growing rapidly. Energy is one of Turkey's most important development priorities. The rapid increase in domestic energy demand has forced Turkey to increase its dependence on foreign energy supplies [35].

Turkey's energy consumption has been growing much faster than its energy production, making Turkey an energy importer. Energy is essential for economic and social development and for an improved quality of life in Turkey [36].

Table 7
Agricultural land and forest area in Turkey between 2005 and 2010 (thousand hectares) [39].

Years	Total utilized agricultural land	Total arable land and land under permanent crops	Total arable land	Sown area	Total land under permanent crops	Land under permanent meadows and pastures	Forest area
2000	38,757	26,379	23,826	18,207	2553	12,378	20,703
2001	40,967	26,350	23,800	18,087	2550	14,617	20,703
2002	41,196	26,579	23,994	18,123	2585	14,617	20,703
2003	40,645	26,028	23,372	17,563	2656	14,617	20,703
2004	41,210	26,593	23,871	18,110	2722	14,617	21,189
2005	41,223	26,606	23,830	18,148	2776	14,617	21,189
2006	40,493	25,876	22,981	17,440	2895	14,617	21,189
2007	39,505	24,888	21,979	16,945	2909	14,617	21,189
2008	39,122	24,505	21,555	16,460	2950	14,617	21,189
2009	38,911	24,294	21,351	16,217	2943	14,617	21,189
2010	39,054	24,437	21,384	16,333	3053	14,617	21,537

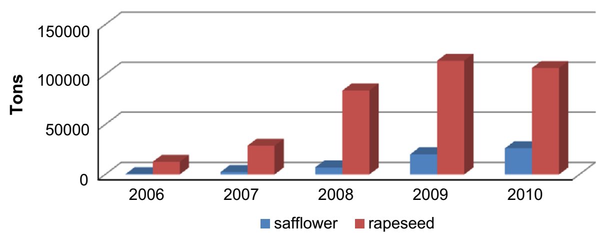


Fig. 13. Production of safflower and rapeseed in Turkey between 2006 and 2010 [39].

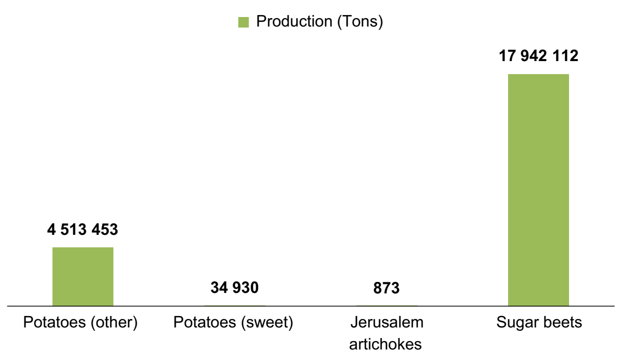


Fig. 14. Potatoes, edible roots and tubers, with high starch or inulin content production in 2010 [39].

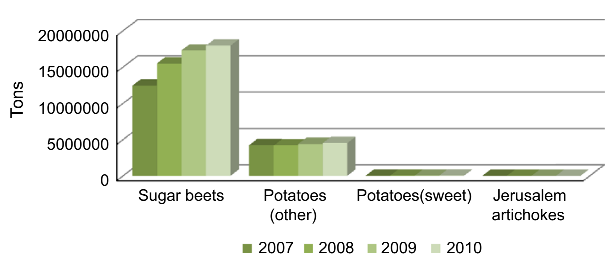


Fig. 15. Other crop products between 2007 and 2010 [39].

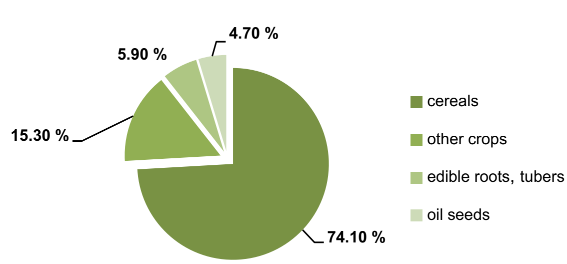


Fig. 16. Amounts of some agricultural products between 2009 and 2010 [39].

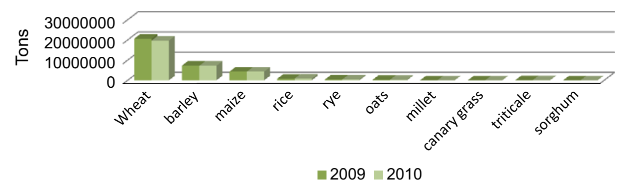


Fig. 17. Cereals and other crop products in 2010 [39].

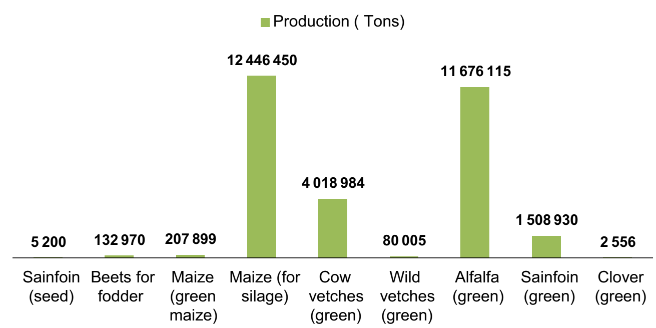


Fig. 18. Fodder crops seed and fodder crops production in 2010 [39].

Table 8
Bioethanol production potential in Turkey in 2009 [44].

Bioethanol plants	Establishment year	Capacity (l/year)	Material
Bursa	2004	40,000,000	Maize
	2007	80,000,000	Sugar beet
Çumra sugar factory	2007	40,000,000	Maize and wheat
Tezkim (Adana)	–	20,000,000	Sugar beet
Eskişehir sugar factory	–		
Ethanol plant (state)			
Eskişehir sugar factory	–	66,500,000	Sugar beet
Erzurum sugar factory	–		
Turhal sugar factory	–		
Malatya sugar factory	–		
Amasya sugar factory (private sector)	–		Sugar beet

3.1. Agricultural products and residues potential of Turkey as a biomass energy source

The importance of agriculture is increasing due to biomass energy being one of the major resources in Turkey. Turkey has great agricultural potential and this makes energy production

Table 9
Field crops and quantity of residues in Turkey [49,50].

Crops	Residue	Total residues (tones)		Utility residue (tones)	Utility (%)	Calorific value (MJ/kg)	Total calorific value (GJ)
		Theoretical	Real				
Wheat	Straw	29,170,785	23,429,907	3,514,486	15	17.90	62,909,300
Barley	Straw	9,992,948	8,963,012	1,344,452	15	17.50	23,527,908
Rye	Straw	405,188	358,04	53,706	15	17.50	939,855
Oat	Straw	419,678	321,236	48,185	15	17.40	838,425
Maize	Stalk	5,911,902	4,970,259	2,982,155	60	18.50	55,169,873
	Stover	596,592	1,907,307	1,144,384	60	18.40	21,056,667
Rice	Straw	582,555	209,532	125,719	60	16.70	2,099,510
	Hull	88,527	77,747	62,198	80	12.98.	807,327
Tobacco	Stalk	362,763	410,778	246,467	60	16.10.	3,968,113
Cotton	Stalk	6,137,181	2,520,281	1,512,169	60	18.20	27,521,470
	Residues	481,527	732,22	585,776	80	15.65	9,167,391
Sunflower	Stalk	2,341,554	2,259,121	1,355,472	60	14.20	19,247,709
Peanut	Straw	127,054					
	Hull	27,621	28,638	22.91	80	20.74	475,155
Soybean	Straw	60,468	21,872	13,123	60	19.40	254,595

from biomass sources necessary. The agricultural total land of Turkey is about 26.350 million ha, of which 38.4% is sown area, 44.1% is forest area, 10.4% is fallow land, and 7.1% is cultivated with fruits and vegetables [37,38]. Table 7 shows the agricultural land and forest area in Turkey between 2005 and 2010 [39].

3.1.1. Biodiesel

Oilseed crops have always been an important segment in Turkey's agriculture. Major oilseed crops are sunflower and cottonseed, and account for over 95% of local production. It also produces groundnut, soybean, sesame, linseed and recently started rapeseed and safflower. Production of safflower in Turkey is going to increase in the years ahead. The biofuels project is one of the most important opportunities for improvement. In the case of production increase, safflower seems most suitable for drought lands [40]. Fig. 12 shows the production of oil seeds in Turkey in 2010 [39].

Vegetable oil is the main raw material used in producing biodiesel. Seventy percent of biodiesel is produced from imported palm oil or its derivatives, although the best oilseeds for biodiesel production in Turkey are safflower and rapeseed [40]. Fig. 13 shows production of safflower and rapeseed in Turkey between 2006 and 2010 [39].

The basic raw material of biodiesel is oil seed and 1.49 million ha (6.2% of cultivated area) area is cultivated for oilseed farming in Turkey. In case of allocating cultivated areas for biodiesel production by contractual and rotation farming especially in sugar beet cultivation areas, canola farming would be realized on an area of 400,000 ha. Furthermore, areas, which are suitable for agriculture but not cultivated (1,897,000 ha), can be used for energy farming through the method of land consolidation. When biodiesel is blended with diesel fuel by 2%, it will enable oilseed farming on an area of approximately 200,000 ha and our fuel import will decrease by 200,000 tones fuel equivalent. A cultivation area of 2,300,000 ha can be put into use if beet rotation and waste areas are used for biodiesel farming in Turkey [41].

3.1.2. Bioethanol

The primary raw materials for bioethanol production in Turkey are: sugar beet and residues, potato, molasses, wheat straw, corn and corn cobs, and lignocellulosic biomaterials [42]. Figs. 14 and 15show, potatoes, edible roots and tubers with high a starch or inulin content production rate in Turkey between 2007 and 2010. In addition to this Figs. 16–18 show the amounts of some agricultural products between 2009 and 2010 [39].

Table 10
Different feedstocks for bioethanol production and their comparative production potential [57].

Feedstock	Bioethanol production potential (l/tone)
Sugarcane	70
Sugar beet	110
Sweet potato	125
Potato	110
Cassava	180
Maize	360
Rice	430
Barley	250
Wheat	340
Sweet sorghum	60
Bagasse and other cellulose biomass	280

Petrol Office (PO) is the only fuel oil company that uses bioethanol in Turkey. Although the legal rate is 5%, PO uses just 2% because of the private consumption tax. According to information from PO, the sale of unleaded fuel (95 octanes) is approximately 600,000 m^3/year and this entire amount is biofuel. In existing circumstances, the ethanol needed is approximately 62,000 m^3/year. The production for this amount of ethanol is 64,500 tones of wheat, 72,500 tones corn or, 210,000 tones of sugar beet. With a regulation about using mixture of ethanol and fuel oil in the private consumption tax, the needed ethanol amount would be 157,000 m^3/year [43]. Table 8 shows the bioethanol production potential in Turkey in 2009 [103].

3.1.3. Biogas

Among the different forms of renewable energy, biomass energy is one of the major resources in Turkey [45]. Since animal husbandry and agriculture are highly developed in Turkey, a substantial amount of animal wastes and agricultural crop residues are produced each year. Organic wastes are of vital importance for the soil, but in Turkey most of these organic wastes are used as fuel through direct combustion. Animal wastes are mixed with straw to increase the calorific value, and are then dried for use. This is the principal fuel of many villages in rural region of Turkey, especially in mountainous regions. Anaerobic digestion for methane production is a possible solution to recover the wastes as fertilizers and produce energy [46]. In Turkey it is necessary to utilize the renewable energy sources to make up for the increasing

energy deficit. As an alternative to these energy sources, the use of biogas seems possible [47].

Biogas can be produced by agricultural materials, such as animal wastes (cattle, chicken, pig, sheep, etc. manures), industrial wastes (slaughter house wastes, blood, fish wastes, etc.), plants′ wastes and residues (corn and corncob, wheat straw, grass, clover, leaves, etc.), and domestic wastes [48].

Turkey is a country which has rich agricultural potential with 23.07 million ha agricultural arable land. About 18.11 million ha is cultivated and the remaining part is fallowing land. The total amount of agricultural solid waste in Turkey is 40–53 million tones and its annual energy equivalent is 50–65 Mtoe (million tones of oil equivalent) [41]. Table 9 shows field crops and quantity of residues in Turkey [49,50].

Biogas technology has been known for a long time, but in recent years the interest in it has significantly increased, especially due to the higher costs and the rapid depletion of fossil fuels as well as their environmental considerations. The main objective of the present study is to investigate the potential of biogas energy in the 15 European Union (EU) countries and in Turkey, which is seeking admission to the EU and is trying to meet EU environmental standards. The biogas energy potential of the 15 EU countries is estimated to be about 800 PJ. Besides this, Turkey′s annual animal waste potential is obtained to be about 11.81 million tones with a biogas energy equivalent of 53.6 PJ [51].

Biogas systems have been widely used in both developed and developing countries and proved their perfection in the economical and technical aspects. Although our country has a big potential in organic waste products used in biogas production, biogas systems have not been widely used in Turkey [52].

4. Classification of energy crops for production of biofuels

Many crop species are multipurpose in that they can be used to produce more than one type of energy product, for example, hemp (both oil and solid biomass) and cereals (ethanol and solid biomass from straw). Some of the more common energy crops are listed below [53].

Cereals (e.g. barley, wheat, oats, maize and rye) can be used to produce ethanol and the straw can be used as a solid fuel. They can also be grown and harvested as a whole crop (grain plus straw) before the grain has ripened and used as a solid fuel or for biogas production feedstock. *Starch* and *sugar crops* (e.g. potato, sugar beet, Jerusalem artichoke and sugarcane): ethanol can be produced from the starch and glucose by fermentation and then used directly as a fuel,

Oil crops (e.g. oilseed rape, linseed, field mustard, hemp, sunflower, safflower, castor oil, olive, palm, coconut and groundnut.) can be used directly as heating fuels or refined to transport biofuels such as biodiesel esters.

Cellulose crops (e.g. straw, wood, short rotation coppice (SRC), etc.): the hemicellulose can be reduced to sugar by acid or enzymatic hydrolysis and then fermented to produce ethanol.

Solid energy crops (e.g. cardoon, sorghum, kenaf, prickly pear, whole crop maize, reed canary grass, miscanthus, willow, poplar and eucalyptus) can be utilized whole to produce heat and electricity directly through combustion or indirectly through conversion for use as biofuels like methanol and ethanol [53].

Numerous crops have been proposed or are being tested for commercial energy farming. Potential energy crops include woody crops and grasses/herbaceous plants (all perennial crops), starch and sugar crops and oilseeds. In general, the characteristics of the ideal energy crop are [54]:

- high yield (maximum production of dry matter per hectare),
- low energy input to produce,
- low cost,
- composition with the least contaminants,
- low nutrient requirements.

Most plants utilise the C_3 photosynthesis route, the C_3 determining the mass of carbon contained in the plant material. Another photosynthesis pathway is represented by C_4 plants, which accumulate a significantly greater dry mass of carbon thando C_3 plants, giving a biomass with increased potential for energy conversion. Examples of the C_3 species are poplar, willow, wheat and most other cereal crops, while the perennial grasses, *Miscanthus,* sweet sorghum, maize and artichoke, all use the C_4 route [54].

C4 plants have a very low compensation point, enabling them to continue photosynthesis at high light intensity when only low carbon dioxide concentrations are available. Besides, because the concentration of CO_2 relative to O_2 in the cells of C4 plants responsible for photosynthesis is higher, the rate of photorespiration in C4 plants is significantly lower than in C3 plants [55].

4.1. Discussion on suitable energy crops for bioethanol

Biofuels originate from plant oils, sugar beets, cereals, organic waste and the processing of biomass. Biological feedstocks that contain appreciable amounts of sugar or materials that can be converted into sugar, such as starch or cellulose can be fermented to produce bioethanol to be used in gasoline engines [56].

Bioethanol feedstocks can be conveniently classified into three types:

- sucrose-containing feedstocks (e.g. sugar beet, sweet sorghum and sugarcane),
- starchy materials (e.g. wheat, corn, and barley),
- lignocellulosic biomass (e.g. wood, straw, and grasses).

Different feedstocks that can be utilized for bioethanol production and their comparative production potential are given in Table 10 [57].

One major problem with bioethanol production is the availability of raw materials for the production. The availability of feedstocks for bioethanol can vary considerably from season to season and depend on geographic locations. The price of the raw materials is also highly volatile, which can highly affect the production costs of bioethanol [58].

Another major problem with bioethanol production is that ethanol production from lignocellulose creates additional technical challenges, such as a need for pre-treatment. Lignocellulosic materials contain cellulose and hemicellulose that are bound together by lignin. Cellulose and hemicellulose are both polymers built up by long chains of sugar monomers, which after pretreatment and hydrolysis can be converted into ethanol by microbial fermentation [59].

4.1.1. Ethanol production from sweet sorghum

Sweet sorghum (*Sorghum biocolor*) has a stem that is rich in moisture and sugar. The juice brix of sweet sorghum is about 15–21%. Thegeneral output of the stems is about 60 tones/ha and that of the seed is 2250–6000 kg/ha [60].

Sweet sorghum is an annual C_4 plant characterized by high photosynthetic efficiency. It is a crop that has a high biomass yield and is rich in carbohydrates. It′s stalks mainly consist of sucrose that amounts up to 55% of dry matter and of glucose (3.2% of dry matter) [61]. They also contain cellulose (12.4%) and hemicellulose (10.2%). Sweet sorghum biomass is rich in readily fermentable sugars and thus it can be considered as an excellent raw material

for fermentative hydrogen production. Overall, out of the many "new crops" that are currently investigated as potential raw materials for energy and industry, sweet sorghum seems to be the most promising one [61]. To date, ethanol and methane are among the best-known microbial products produced from sweet sorghum. Specifically, the energy yield from ethanol obtained from the above referenced studies ranged between 6500 and 8900 kJ/kg dry and 1400 and 2700 kJ/kg fresh sorghum biomass, respectively (assuming that the energy yield from ethanol is 26,500 kJ/kg) [61].

Sweet sorghum is less economically important for refined sugar production than other sugar crops, e.g., sugar beet and sugarcane, but can produce more raw fermentable sugar under marginal conditions than those crops [62]. The net result of these factors is that sugar ethanol production from sweet sorghum outperforms biofuel production from most starch and oil fuel crops in terms of land use efficiency, water productivity, and overall energy balance and is comparable to sugarcane ethanol [62].

In spite of this, the energy required to produce raw sorghum juice for ethanol production is less than that required to convert other major sugar crops, e.g., sugarcane and sugar beet, to a fermentable state. As a root crop, more effort is required for harvesting sugar beets, and sugarcane can be grown only in tropical regions. It is true that these crops may yield more sugar and biomass than sweet sorghum under ideal conditions [63]. However, sweet sorghum performs well under adverse conditions, and requires fewer inputs to achieve its maximal production. Its nutrient requirements are low, although rainfall levels do affect total biomass production; sorghum uses less water per unit biomass produced than many other C4 plants [63].

Sweet and fibre sorghum (*Sorghum bicolor* (L.) Moench) are multipurpose cereals of potential interest for several non-food uses. Sweet and fibre sorghum, multi-purpose cereals in the frame of non-food agriculture, have proved suitablecrops in order to drain excessive soil nitrogen reserves, otherwise producing too high a nutrient load for the environment to cope with [27]. Growing an energy crop involves a careful consideration of its various implications: the crop should be economically appealing, environmentally safe, have a high energy efficiency, and contribute as a CO_2 sink to counterbalance the earth's gas emissions to the atmosphere. Both annual and perennial species are potential energy crops. Among the former, sweet and fibre sorghum rank high in temperate to warm areas, thanks to the good yield potential achieved under conditions of limited water supply [64].

Sweet sorghum is one of the most drought resistant agricultural crops as it has the capability to remain dormant during the driest periods. Of the many crops being investigated for energy and industry, sweet sorghum is one of the most promising candidates, particularly for bioethanol production principally in developing countries [65].

Sweet sorghum is a C4 plant with the following interesting characteristics [66]:

- its growth cycle is short (about four months) facilitating double cropping,
- it can be easily grown from seeds,
- its production can be completely mechanized,
- it can produce sugar in the stalk and starch in the grain,
- it has a high water and nutrient use efficiency,
- the bagasse produced from sweet sorghum has high biological value when used as forage,
- it has a wide adaptability to different environments.

4.1.2. Ethanol production from starch, corn, other starchy materials

Feedstock for bioethanol essentially comprises sugarcane and sugar beet [67]. Two-third of world sugar production is from sugarcane and one-third is from sugar beet [65]. The advantages of sugar beet are a lower cycle of crop production, higher yield, and high tolerance of a wide range of climatic variations, low water and fertilizer requirement. Compared to sugarcane, sugar beet requires 35–40% less water and fertilizer [65].

Themain feedstock for ethanol production is sugarcane in the form of either cane juice or molasses. About 79% of ethanol in Brazil is produced from fresh sugarcane juice and the remaining percentage from cane molasses. Sugarcane molasses are the main feedstock for ethanol production in India; cane juice is not presently used for this purpose [68].

- Sugarcane, *(Saccharum officinarum)*, is a perennial grass in the Poaceae family, a C4 plant with high photosynthesis efficiency and yield potential. Sugar beet (*Beta vulgaris* L.), a member of the Chenopodiaceae family, is a plant whose root contains a high concentration of sucrose. Sugar beet (1 ha) could produce 30–60 tones of root tuber, containing 14–21% of sugar [60].
- As one of the major C4 crops, maize (Zea mays) offers promise in this regard. Compared to other crops with biofuel potential, maize can provide both starch (seed) and cellulosic (stover) material for bioethanol production. However, the combination of food, feed and fuel in one crop, although appealing, raises concerns related to the land delineation and distribution of maize grown for energy versus food and feed. To avoid this dilemma, the conversion of maize biomass into bioethanol must be improved. Maize stover (leaves and stalks) constitutes to a large part of the agricultural biomass. Ethanol production from non-grain portions of plants is referred to as cellulosic or lignocellulosic ethanol. Lignocellulose is composed of 30% hemicellulose, 44% cellulose and 26% lignin [69].
- Sweet potato (*Ipomoea batatas*) is a dicotyledonous crop plant which belongs to the family Convolvulaceae, has large, starchy, sweet tasting tuberous roots. It has a high yield of biomass, good biotic stress resistance and good adaptability. Yields of 19.5–37.5 tones/ha can be normally obtained, with up to 60 t/ha in high yielding lands with good management [60].

Sweet potato, a non-grain crop that is rich in starch, is a promising feedstock for fuel ethanol production. Recent studies have shown that sweet potatoes can yield 2–3 times more ethanol than corn, nearly the amount that sugarcane can produce [70]. China is the biggest producer of sweet potatoes in Asia and throughout the globe. With a stable annual production of more than 100 million tones, China produces greater than 80% of the world's sweet potato crop [71].

- Jerusalem artichoke, is a tuberous-rooted perennial (*Helianthus tuberosus*) of the family Asteraceae, native to North America, is a plant whose tuber is rich in synanthrin and other fructose polymers constituting 3–60 fructose units and one glucose unit. The inulin content in fresh tuber is about 10–20% with an average of 15% [60].

  The Jerusalem artichoke is a possible carbohydrate resource for the production of bioethanol and biogas due to its advantages over the traditional agricultural crops. These advantages include good growth in poor soil, high tolerance to frost and plant diseases and very high carbohydrate yield per acre. The artichoke tubers could be derived from perennial energy plantations with minimal or no fertilizer requirements. Jerusalem artichoke can be adapted to widely differing climatic and soil conditions, therefore it could be a sustainable crop for energy production in Europe. Laboratory testing of anaerobic digestibility of Jerusalem artichoke stillage left over after ethanol distillation has shown that the stillage has high biological value and biogas potential: it can serve as biogas feedstock in the future. This new

applications for this by-product stream could reduce the energy consumption of bioethanol production based on Jerusalem artichoke in the coming years [72].

- Cassava (*Manihot esculenta*) is a woody shrub of the Euphorbiaceae, native to South America. It is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root, a major source of carbohydrates [73]. Cassava represents an important alternative source of starch not only for ethanol production, but also for production of glucose syrups. In fact, cassava is the tuber that has gained the most interest due to its availability in tropical countries, being one of the top ten more important tropical crops. Ethanol production from cassava can be accomplished using either the whole cassava tuber or the starch extracted from it [74]. Besides corn and wheat, ethanol can be produced from rye, barley, triticale, and sorghum. For these cereals, some pretreatments have been proven to be useful. Byemploying the pearling of wheat, barley, rye and triticale grains for increasing the starch content of the feedstock in an average of 12% gives a 6.5–22.5% increase in ethanol yield during fermentation [68].

4.1.3. Ethanol production from main perennial rhizomatous grasses

There are many ecological benefits expected from the production and use of perennial grasses. The substitution of fossil fuels or of raw materials based on fossil fuels by biomass is an important contribution to reduce anthropogenic CO_2 emissions. Compared to other biomass sources, like woody crops and other C3 crops, C4 grasses may be able to provide more than twice the annual biomass yield in warm and temperate regions because of their more efficient photosynthetic pathway [75].

Grass is an excellent energy crop; it may be classified as a high yielding, low energy input, and perennial crop. Numerous farmers across Europe (in particular Germany and Austria) use grass silage as a feedstock for biogas production; in a number of cases the produced biogas is scrubbed to biomethane and used as a transport fuel or injected into the natural gas grid [76]. In Europe, about 20 perennial grasses have been tested and four perennial rhizomatous grasses (PRG), namely miscanthus (*Miscanthus* spp.), reed canary grass (*Phalaris arundinacea*), giant reed (*Arundo donax*) and switchgrass (*Panicum virgatum*) were chosen for more extensive research programs. Reed canary grass and giant reed are grasses with the C_3 photosynthetic pathway, and are native to Europe [77].

- Miscanthus, which originated in Southeast Asia, and switchgrass, native to North America, are both C_4 grasses. These four grasses differ in their ecological/climatic demands, their yield potentials, biomass characteristics and crop management requirements. Efficient production of bioenergy from such perennial grasses requires the choice of the most appropriate grass species for the given ecological/climatic conditions. In temperate and warm regions, C_4 grasses out yield C_3 grasses due to their more efficient photosynthetic pathway. However, the further north perennial grasses are planted, the more likely these cool season grasses are to yield more than warm season grasses. Low winter temperatures and short vegetation periods are major limitations to the growth of C_4 grasses in northern Europe. With increasing temperatures towards central and southern Europe, the productivity of C_4 grasses and therefore their biomass yields and competitiveness increase [77].
- *Miscanthus* is a high yielding bioenergy crop. Lignocellulosic plant material is one of the most abundant biomass resources. The sugars contained in the lignocellulose can be fermented into ethanol. The accessibility of these sugars vary among plant species, but are often difficult to access due to the lignin seal of the lignocellulose structure. *Miscanthus* possesses the C4 photosynthetic pathway. Compared to C3-plants that make up the majority of plants, C4-plants have a high carbon dioxide fixation rate, which allows for high rates of photosynthesis. The C4-plants can, therefore, grow very fast [55].
- Switchgrass (*Panicum virgatum* L.) is a broadly adapted warm-season grass species native to most of the central and eastern United States. Switchgrass has been identified as a potential biofuel species because it is a native species that requires minimal management, and has a large potential to sequester carbon underground. Switchgrass is a common perennial C_4 grass that is widely distributed across North America. Ecologically, this species is a dominant plant in the central Great Plains grasslands, with an impact on both the structure and function of these ecosystems [78].

Practically, switchgrass is an important forage crop in pasture lands, and has been studied extensively over the past two decades for its potential value as an alternative energy source. In recent years, switchgrass has become a model species for biofuel production [79].

Switchgrass was chosen as a prospective biofuel for its ability to increase soil quality, sequester carbon, and its wide range of suitable habitat [80]. While the potential economic benefits of implementing switchgrass for biofuel production are enormous, the environmental consequences of its cultivation must be considered [81].

In the near future, the lignocellulosic C_4 crops *Miscanthus* and switchgrass (*Panicum virgatum*) are unlikely to outcompete sugarcane (*Saccharum officinarum*) in the net yearly energy yield of transport biofuel ha^{-1}. This holds true for both for the thermochemical conversion into liquid hydrocarbons and the enzymatic conversion into ethanol. Currently, *Miscanthus* and switchgrass would also not seem able to outcompete corn (Zea mays) in the net yearly energy yield of liquid transport biofuel ha^{-1}, but further development of these lignocellulosic crops may gradually lead to a different outcome. There is substantial evidence that a rapid expansion of liquid biofuel production for transport from food crops has an upward effect on food prices [82].

Non-food crops proposed in this context are mainly crops that can provide lignocellulosic biomass for transport biofuel production. These include grasses such as *Miscanthus* and switchgrass and woody crops such as willow [83,84].

It would seem that in the near future the C_4 lignocellulosic crops *miscanthus* and switchgrass are unlikely to outcompete sugarcane in the net yearly energy yield of liquid transport biofuel yields ha^{-1}. Currently, in temperate climates *miscanthus* and switchgrass are unlikely to outcompete corn (*Z. mays*) in the net yearly energy yield of liquid transport biofuel ha^{-1}, but this may gradually change in the future due to further development of the C_4 lignocellulosic crops. A view of the large differences in net biomass yields is presented in Table 11 [82].

Switchgrass has become a main focus for research over other types of energy crops because yields are higher and production costs are lower. The benefit of switchgrass over other types of energy crops is its tolerance to droughts and adaptability to many types of soils and climates. Unlike many traditional crops, switchgrass is a perennial so it does not need to be planted each year. Once established it can be harvested up to two times in a season. Switchgrass reaches full yield capacity after 3 years. Its permanent root system can extend over 10 feet into the ground and coupled with its large temporary root system it can improve soil quality through increased water infiltration and “nutrient-holding capacity”.

Table 11
Estimated net feedstock yields from four C4 crops [82].

Crop	Yield of dry matter (Mg ha^{-1} year^{-1})	Biomass to be returned to soil (Mg year^{-1})	Correction factor for input of fossil fuels	Net yield to displace mineral oil by biofuels (Mg dry weight ha^{-1} year^{-1})
Sugarcane	36.8	3	0.97	31.8
Miscanthus	10–13	3	0.98	7–10
Corn	17–18	3	0.8	11–12
Switchgrass	10–15	3	0.98	7–12

Table 12
Oil species for biodiesel production [27].

Group	Source of oil
Major oil	Coconut (copra), corn (maize), cottonseed, canola (a variety of rapeseed), olive, peanut (groundnut), safflower, sesame, soybean, and sunflower
Nut oils	Almond, cashew, hazelnut, macadamia, pecan, pistachio and walnut
Other edible oils	Amaranth, apricot, argan, artichoke, avocado, babassu, bay laurel, beech nut, ben, Borneo tallow nut, carob pod (algaroba), cohune, coriander seed, false flax, grape seed, hemp, kapok seed, lallemantia, lemon seed, macauba fruit (*Acrocomia sclerocarpa*), meadow foam seed, mustard, okra seed (hibiscus seed), perilla seed, pequi, (*Caryocar brasiliensis* seed), pine nut, poppy seed, prune kernel, quinoa, ramtil (*Guizotia abyssinica* seed or Niger pea), rice bran, tallow, tea (camellia), thistle (*Silybum marianum* seed), and wheat germ
Inedible oils	Algae, babassu tree, copaiba, honge, jatropha or ratanjyote, jojoba, karanja or honge, mahua, milk bush
Other oils	Castor, radish, and tung

Table 13
Potential biodiesel yield from triglyceride feedstock [27].

Source	Potential annual yield (gallons/acre)
Corn	18–20
Cotton	35–45
Soybean	40–55
Mustard	60–140
Camelina	60–65
Safflower	80–85
Sunflower	75–105
Canola	110–145
Rapeseed	110–130
Jatropha	140–200
Coconut	250–300
Palm oil	400–650

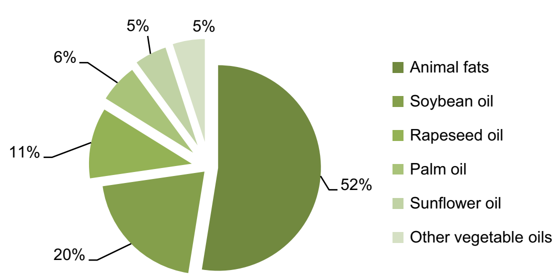


Fig. 19. The oil and fat feedstock distribution of the top 10 developed countries with self-sufficiency potential in 2006 [89].

The benefits of switchgrass are summarized below [85];

- It requires ¼ of the water and fertilizer used for traditional crops, such as corn,
- It can grow up to 10 feet in the season,
- Its extensive root system can help prevent soil erosion
- It is resistant to pests and diseases

Switchgrass uses C_4 carbon fixation, giving it an advantage in conditions of drought and high temperature [86]. Unlike corn, switchgrass can grow on marginal lands and requires relatively modest levels of chemical fertilizers [87].

Perennial grasses have many benefits as bioenergy crops. The simplest way to think of grass is as an efficient and fast growing solar energy collector that is relatively easy to grow, harvest, and process. Grasses not only sequester and store vast amounts of carbon in the root systems and soil, but conveniently occur globally in a wide range of geographies, climates, and soil types [88].

4.2. Discussion on suitable energy crops for biodiesel

Commonly, it is accepted that biodiesel raw materials include the oils from soybean, canola, corn, rapeseed, and palm. New plant oils under consideration include mustard seed, peanut, sunflower, and cotton seed [27].

A variety of bio lipids can be used to produce biodiesel. These are,

- virgin vegetable oil feedstock; rapeseed and soybean oils are most commonly used, though other crops such as mustard, palm oil, sunflower, hemp, and even algae show promise
- waste vegetable oil
- animal fats including tallow, lard, and yellow grease
- non-edible oils such as jatropha, castor oil, and tall oil [89].

More than 350 oil-bearing crops have been identified, of which only soybean, palm, sunflower, safflower, cottonseed, rapeseed, and peanut oils are considered potential alternative fuels for diesel engines [27]. Table 12 shows the oil species that can be used in biodiesel production [27]. In addition, Table 13 shows the potential biodiesel yield from triglyceride feedstocks [90]. Also, Fig. 19. shows the oil and fat feedstock distribution of the top 10 developed countries with self-sufficiency potential in 2006 [89].

- Rapeseed (*Brassica napus*) is the most cultivated energy crop in Europe grown for the biofuel, food and fodder industry. Rapeseed's high oil yield is attributed to its high cellulosic content [91] and, consequently, rapeseed is at the moment the first option for biodiesel production [92], while it may be the only, at the moment, able to be used without prior treatment as liquid biofuel.

- Currently the oil from jatropha (*Jatropha curcas*) seeds is used for making biodiesel fuel in Philippines and in Brazil, where it grows naturally and in plantations in the southeast, north, and northeast of Brazil. Likewise, jatropha oil is being promoted as an easily grown biofuel crop in hundreds of projects throughout India and other developing countries [12]. Once the seeds have been pressed, the remaining cake can be used as the feed in digesters to produce biogas for cooking and in engines, or as fertilizer and sometimes even as animal fodder. The whole seed (with oil) can also be used in digesters to produce biogas.
  The raw materials used at present in India are, *Jatropha curcas* (jatropha) and *Pongamia pinnata* (karanja). Oils from both the plants contain toxins and hence are non-edible. Jatropha and karanja seeds possess 40% and 33% oil, respectively [93].
- Palm oil whose botanical classification is *Elaeis guineensis* is native to West Africa where it was growing wild and was later developed into an agricultural crop. Palm oil is a tropical perennial plant and grows well in lowland with humid climates and therefore can be cultivated easily in Malaysia. The tree which is unbranched and single-stemmed can grow up to 20–30 m height [94]. The flowers are produced in dense clusters where each individual flower is small with three sepals and three petals. The leaves are pinnate and can reach between 3 and 5 m long.
- Safflower (*Carthamus tinctorius L.*) seed oil was chemically treated by the transesterification reaction in methyl alcohol environment with sodium hydroxide (NaOH) to produce biodiesel. The produced biodiesel was blended with diesel fuel by 5% (B5), 20% (B20) and 50% (B50) volumetrically [95].
  Safflower which belongs to the Composites family is cultivated in several parts of the world due to its adaptability to different environmental conditions. It is highly branched, herbaceous, thistle-like annual plant, usually with many long sharp spines on the leaves. The plants are 30–150 cm tall with globular flower heads and commonly, brilliant yellow, orange or red flowers which bloom in July. Each branch will usually have from one to five flower heads containing 15–20 seeds per head [96].
- Soybean *(Glycine max)* is the most important source of protein and oil worldwide. It is widely cultivated in a number of countries, with the major producers being the US (33%), Brazil (27%), Argentina (21%) and China (7%). Soybeans are a valuable source of protein and oil. The protein is primarily used as feed, with some food applications, while the oil is more broadly incorporated into food, feed, and some industrial applications. Soybean is one of the main raw materials used for biodiesel production. In Brazil, soybean is responsible for over 80% of all biodiesel produced. In Argentina it represents 100%, in the United States about 74% and in the European Union only 16%. Therefore, soybean is a promising source for biodiesel production. As the demand for soybean oil and protein increases, the improvement of soybean quality and production through genetic breeding has become an important issue [24].

4.3. Discussion on suitable energy crops for biogas

Anaerobic digestion can be applied to convert plant biomass, crop residues and energy crops, i.e. plants grown specifically for the purpose of producing energy, to a methane-rich biogas, a carbon-neutral source of domestic renewable energy [97].

Biogas is methane produced by the process of anaerobic digestion of organic material by anaerobes. It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. The solid by-product, digestate, can be used as a biofuel or a fertilizer. Biogas can be recovered from pre-treatment waste processing systems [98].

Methane production from a variety of biological wastes through anaerobic digestion technology is growing worldwide and is considered ideal in many ways because of its economic and environmental benefits [99]. The uses of biogas are as follows:

- it is produced from renewable resources,
- it does not add any greenhouse gases in the atmosphere,
- it is produced locally without any dependency on foreign oil or natural gas supplies,
- it helps in reducing the pollution produced by the organic wastes, which account for most fresh water pollution,
- it helps in retarding waste management problems [99].

Energy crops and crop residues can be digested either alone or in co-digestion with other materials and by employing either wet or dry processes. In the agricultural sector one possible solution to processing crop biomass is co-digestion together with animal manures, the largest agricultural waste stream. In addition to the production of renewable energy, controlled anaerobic digestion of animal manures reduces emission of greenhouse gases, nitrogen and odour by manure management, and intensifies the recycling of nutrients within the agriculture [100,101].

Biogas production is of major importance for the sustainable use of agrarian biomass as a renewable energy source. Economic biogas production depends on high biogas yields. For this reason, it should be considered and also research should be done on the suitability of different crop species and varieties, optimum time of harvesting, specific methane yield and methane yield per hectare [102].

The key factors for a maximum biogas yield are species and variety of energy crops, time of harvesting, mode of conservation and pre-treatment of the biomass prior to the digestion process and also the nutrient composition of the energy crop. Guidelines on optimum energy crop production, optimum harvesting time, optimum nutrient composition, optimum conservation and pre-treatment technology must be developed [102].

With biogas production, another key factor to be optimised is the methane yield per hectare. This may result in different harvesting strategies when growing energy crops for anaerobic digestion are 0compared to growing them as a forage source for ruminants. Specific harvest and processing technologies and specific genotypes are required when crops are used as a renewable energy source [102].

Energy crops can be used to feed anaerobic digesters and produce renewable energy. However, the sustainability of this option requires that it contributes to a net production of renewable energy and a net reduction of fossil CO_2 emission. In the agriculture sector, energy crops can represent a valuable alternative to exogenous energy-rich wastes [103].

In Germany for example, the number of digesters using energy crops has increased from about 100 in 1990 to nearly 4000 in 2008. Numerous plants and plant materials have been tested for their methane formation potential. In principal many varieties of grass, clover, cereals and maize including whole plants, as well as rape or sunflower proved feasible for methane production. Even hemp, flax, nettle, miscanthus or potatoes, beets, kale, turnip, rhubarb and artichoke were tested successfully. [104].

Biogas production from energy crops is of growing importance [22]. Maize, sunflower, grass and sudan grass are the most commonly used energy crops.

With energy production as the main objective of anaerobic digestion, the type of feedstock used for anaerobic digestion is highly relevant because the biogas yield obtained per cubic meter of reactor volume depends on the energy density and biologic degradability of the applied feedstock. Therefore, the use of energy

Table 14
Exemplary methane yields from digestion of various plants and plant materials as reported in the literature [104].

Methane yield (m^3 per tone volatile solids)			
Maize (whole crop)	205–450	**Barley**	353–658
Wheat (grain)	384–426	**Triticale**	337–555
Oats (grain)	250–295	**Sorghum**	295–372
Rye (grain)	250–295		
Grass	298–467	**Alfalfa**	340–500
Clover grass	290–390	**Sudan grass**	213–303
Red clover	300–350	**Reed Canary Grass**	340–430
Clover	345–350	**Ryegrass**	390–410
Flax	212	**Nettle**	120–420
Sunflower	154–400	**Miscanthus**	179–218
Oilseed rape	240–340	**Rhubarb**	320–490
Jerusalem artichoke	300–370	**Turnip**	314
Peas	390	**Kale**	240–334
Potatoes	276–400		
Sugar beet	236–381	**Chaff**	270–316
Fodder beet	420–500	**Straw**	242–324
Hemp	355–409	**Leaves**	417–453

crops is an interesting alternative to fermentation Fresh energy crops or silage can be used as the substrate in most existing digester designs. Precautions have to be taken when cellulosic crop material is going to be used. Cellulosic feedstock is rather slowly to degrade. And also, cellulosic fibres can block pumps, pipes or even the mixing equipment of the digester. The advantage is that, biogas can be produced from plants not being competitive with production. Even soils, not suitable for food production, can be used for the cultivation of energy crops [104].

Maize is widely used in Germany as a feedstock for biogas plants. Here the maize is harvested, shredded and then placed in silage clamps from which it is fed into the biogas plants. Suitable substrates for the digestion in agricultural biogas plants are energy crops, organic wastes, and animal manures. Maize (*Zea mays* L.), herbage (Poacae), clover grass (*Trifolium*), Sudan grass (*Sorghum sudanense*), fodder beet (*Beta vulgaris*) and others may serve as energy crops [105].

Maize is the most dominating crop for biogas production. Maize is considered to have the highest yield potential of field crops grown in Central Europe. The things still open to question are the quality needs, the yield potential considering the given limits in water availability and thermal time and the integration of energy maize in sustainable cropping systems to minimize negative effects on the environment and to maximise net energy yield [105].

As Table 14 shows that alfalfa (*Medicago sativa* L.) has considerable potential as a feedstock for the production of fuels and in addition feed, and industrial materials. However, unlike other major field crops such as corn and soybeans, which are commonly refined for production of fuel and industrial materials, the refining of alfalfa remains undeveloped. Instead, alfalfa is primarily processed and used on-farm in the form of dried hay, silage, and fresh forage known as "green chop," or is grazed by animals in pastures [106].

5. Conclusion

Energy crops that are suitable for biofuel production have been identified based on their biological characteristics, environmental requirements, developmental status, the type of farming system and natural geographic conditions [60].

Olean n the other hand, energy crops could provide

- A cenergy biofuels alternative for power plants
- feedstocks for ethanol (cellulose or sugar, starch plants) and biodiesel
- new cash crops to farmer and rural economic development
- greater energy independence
- productive use of environmentally damaged lands [107].

Biofuels, one of the renewable energy resources, have interesting impacts such as the reduction of external dependence in terms of energy, their development and environmental benefits, and providing of the feed, food and raw material industries with raw materials.

According to Reports 2011 and 2012 by the IEA, the inconsistency in world's fuel prices, the energy demand security and the reasons with respect to the global climate change are the fundamental compelling factors in seeking alternatives to the fossil fuels which meet 80% of the world's energy needs. The fuel need of the transportation sector is met by liquid and fossil fuels, and about 57.6 Mtoe or 2.4% of the fuel need of this sector is met by the ethanol produced from sugarcane, corn and other cereal groups and by the biodiesel produced from oilseed plants.

Despite the concerns about the impacts of bioenergy, there is growing interest in biofuels in the transportation sector worldwide, and their production is also gradually increasing in comparison with the production of conventional fuels.

According to the Alternative Policy Scenario by the IEA, it is estimated that the sum of biofuel production might reach approximately 7% of the highway transport in 2030.

Even with this great increase in production, the participation of biofuels in agricultural production will go on being relatively modest.

According to Report 2007 by the IEA, the arable land requirement for liquid biofuel production is estimated to increase from 14 Mha in 2004 – or only 1% of the world's arable land – to 53.0 Mha in 2030 – or 3.8% of the land used for agriculture – depending, to a great extent, on raw materials.

Most of the developed countries supply their energy needs from biofuels in amounts which increase with every passing year. While the U.S.A. uses corn as the raw material in bioethanol production, Brazil, the leader in bioethanol production, uses sugarcane. The EU, Indonesia, Brazil, Argentina and the U.S.A., the basic biodiesel producers of the world, use palm oil, rapeseed, and soybean as raw materials for biodiesel. In addition, Germany, the leader in biogas production, widely uses corn as the raw material in biogas plants.

The population of Turkey has been rapidly increasing in recent years. Consequently, the increasing energy needs urge one to be oriented to searches for new resources and biofuels. Therefore, the production of biofuels from energy crops that are renewable energy resources and particularly the use of conventional crops and their residues as raw materials should be increased in Turkey so as to reduce external dependence in terms of energy and to prevent the increase in the greenhouse gas emission. In parallel with this, legal regulations on biofuel production should be considered. Moreover, the current agricultural policies in Turkey should be developed.

Considering the environmental pollution, according to the UNFC, Turkey is by far in the top rank in terms of the ratio of carbon dioxide and other greenhouse gases emitted in the list of 41 industrialized countries.

However, in spite of having the potential for a wide range of agricultural products, Turkey supplies the majority of its energy needs and its oil needs by importing. Thus, the production of biofuels from energy crops is particularly important to Turkey.

In this regard, this study provides a perspective on the potential for the production of biofuels from energy crops in Turkey. The study investigates the current potential for raw materials in Turkey, the provision of sustainability, and the ensuring of sustainable biofuel production.

In 2011, the Energy Market Regulatory Authority (EPDK) decided to increase the rates of biodiesel and bioethanol to be obtained from local products as of 2013. According to this decision, the production of bioethanol from regional agricultural resources to meet the fuel need will be at least 2% in 2013 and 3% in 2014. A similar decision was also taken for biodiesel. When biofuels in the near future of Turkey are taken into consideration, it appears distant to meet the needs with the current production.

According to the result of this study, it is recommended that the promising energy crops be mapped to determine the potential for arable land for the dissemination of plant cultivation for biofuel production.

To provide raw materials for biofuel production, it is important to widely use non-arable land and the convenient plants which can be adapted to the Turkish geography, such as sweet sorghum and switchgrass. Additionally, saffron and rapeseed are the most convenient easily-cultivated plants for biodiesel production in Turkey.

Besides, the production of biogas as a renewable energy resource in Turkey is of great importance in terms of its potential for agriculture. Moreover, a considerable rate of energy crops as well as agricultural residues, animal manure and any organic waste can be used as raw materials for biogas production. Furthermore, biogas production will have a useful effect on economic, ecological and social development particularly in the rural regions of Turkey.

In conclusion, the obtaining of biofuels especially from nonfood energy crops and the investigation of new energy crops as raw materials have been increasing by becoming widespread both in the world biofuel sector and in scientific studies. The recent studies on the obtaining of biofuels from energy crops show that there will be new, promising energy crops to be used as raw materials upon the development of biomass conversion technologies and of the pretreatments applied to biomass in the future.

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